J. Indian Water Resour. Soc.,
Vol. 37, No. 4, Oct., 2017

DECADAL RAINFALL AND PROBABILISTIC ESTIMATION OF ONE DAY MAXIMUM RAINFALL OF SILCHAR, ASSAM

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ABSTRACT

The success or failure of crops, controlling devastating floods and drainage especially for Assam is intimately intertwined with the amount and distribution of rainfall. So, the daily rainfall data of 10 years (2003-2012) was analysed and annual one day maximum rainfall (ADMR) of Silchar, Assam was sorted to estimate the probable ADMR for different return periods. The decadal rainfall pattern was studied, observed values of ADMR were estimated by Weibull's plotting position and the expected values were estimated by the probability distribution functions viz., Normal, Log-Normal, Gumbel and Generalized Extreme Value. The expected values were compared with the observed values and goodness of fit was determined by χ^2 (chi-squared) test. The results concluded Gumbel distribution to be the best fit probability distribution to forecast ADMR for different return periods of Silchar. Based on the best fit probability distribution, a minimum rainfall of 102.69 mm in a day can be expected to occur with 90.19% probability, 1.1 year return period and a maximum of 177.79 mm rainfall can be received with 9.09% probability, 11 years return period. The results of this study can aid in proper designing of soil and water conservation structures, drainage systems and crop planning and management in Silchar, Assam.

Keywords: *Annual one day maximum rainfall, Return period, Frequency, Probability distribution.*

INTRODUCTION

Rainfall is of paramount importance among the hydrological components and the major source of water to earth. The occurrence and distribution of rainfall is erratic with temporal and spatial oscillations in nature (Singh *et al*., 2012). Various hydraulic structures, like flood control structures, soil and water conservation structures, sewage systems, drains and culverts are designed on the basis of the probability of occurrence of extreme rainfall events and the subsequent runoff generated, rather than on the basis of their mean value (Vivekanandan, 2009). When the rainfall during a period of year is insufficient or ill distributed, it becomes hard-hitting for the crops to meet their required evapotranspiration (ET) leading to crop failure. Conversely, if the rainfall is too high as compared to the rate of infiltration of soil, it generates higher rate of runoff, with further repercussions of landslides, flood and debris disaster. Hence being cognizant about rainfall pattern, distribution and maximum amount over a particular area/catchment becomes imperative to aid in proper planning and design of various flood control and soil and water conservation structures (Ray *et al.,* 2014).

Severe hydrological occurrences like flood and drought can have disastrous impact on the society. Extreme rainfall is the primary cause of flood and owing to this, prediction of 24-hour maximum rainfall is a prerequisite (Subramanya, 2009). As rainfall related phenomena are stochastic processes, frequency analysis and probability theory are extensively used for estimation of expected rainfall and return periods (Bhakar *et al*., 2008). The probability distribution functions most commonly employed to estimate rainfall return period and expected rainfall include Normal, Log Normal (LN), Gumbel, Generalized Extreme Value (GEV) to name a few. After the frequency analysis the best fit method for rainfall estimation can be further zeroed on by various methods like Chi squared test, Kolmogorov-Smirnov test, Anderson-Darling test and Least squared test (Sharma and Singh, 2010).

Singh *et al*. (2012) analysed the rainfall data by Normal, LN, Log-Pearson Type-III (LP-III), Gumbel distributions and concluded that LP-III distribution was the best fit probability distribution to forecast annual one day maximum rainfall for different return periods of Jhalarapatan area of Rajasthan, India. Rao and Kao (2006) tested Gumbel, GEV, Pearson Type III (P-III), LP-III, and Pareto distributions and thereby selected GEV distribution to be the suitable one for Indiana rainfall data in United States. Frequency analysis of rainfall data has been done for different places in India (Singh *et al*., 2012; Agarwal *et al*., 1988; Rizvi *et al*., 2001). But no such analysis has been carried out for Silchar, Assam to address the problem related to flood, drainage and crop planning.

Scientific prediction of maximum rainfall with recurrence periods can aid to avert catastrophic floods, especially for vulnerable areas which are susceptible to rainfall of high intensity, Silchar area of Assam, India being one such. So, in the present study, it has been endeavoured to determine the annual one day maximum rainfall (ADMR) with the help of four different probability distribution functions, *viz,* Normal, Log Normal, Gumbel and Generalized Extreme Value distribution for Silchar.

MATERIALS AND METHODS

Study area

Silchar is situated in the southern part of Assam in north-eastern part of India at 24.83° N, latitude and 92.78° E, longitude (Fig.1). The region experiences a tropical climate with hot and humid summer interspersed with torrential rainfall and thunderstorms. Silchar is frequently inundated due to excessive rainfall and floods by river Barak (Fig. 2). With a total of 28 wards under Silchar Municipality Board (Cachar district), it is the second-largest town of Assam. The relative humidity of the region ranges from 65-70% during winter and 90-95% during rainy season. The maximum temperature of the region ranges from 35-37 °C during summer and 9-11 °C during winter. A high rainfall belt with average annual rainfall of 2800 mm encloses Silchar.

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Manuscript No.: 1443

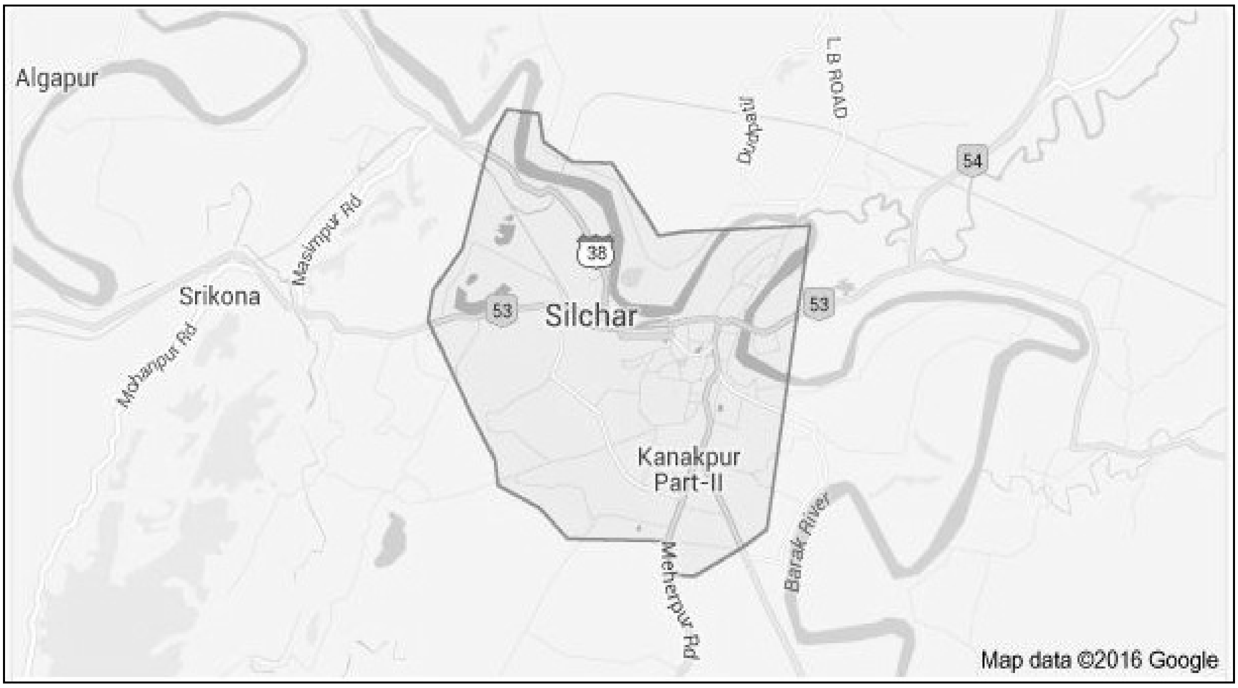

Fig 1: Location of the study area, Silchar (*Source: Google maps)*

Fig 2: An aerial view of Silchar with Barak river at full flow
(*Source:* *https://en.wikipedia.org/wiki/File:Silchar_barak.jpg*)

Data collection and analysis

Daily rainfall data (2003-2012) gauged at E and D Colony, Silchar (sourced from *Silchar Water Resource Department, Government of Assam*) were used for the present study. Annual maximum daily rainfall data was sorted out from the above collected data (Table 3) and the variability of the hydrological series was described by computing the statistical parameters: mean, maximum and minimum value, standard deviation, coefficient of variation (C_v) and coefficient of skewness (C_s).

From the data, values of annual one day maximum rainfall (ADMR) were taken for the study purpose. Return period or recurrence interval (T) which is the average interval of time within which any extreme event of given magnitude will be equalled or exceeded at least once (Suresh, 2005) was calculated using Weibull's plotting position method after having arranged the ADMR in descending order, each having a corresponding rank:

$$T = \frac{N+1}{m} \qquad \dots (1)$$

Where N is the total number of years of record and m is the rank of observed rainfall values arranged in descending order. The probability of exceedance (p) of rainfall values is the reciprocal of the return period.

Frequency analysis

On the basis of theoretical probability distributions, the upcoming rainfall of various magnitudes and different return periods was predicted. The probability distribution functions used in this study Normal, Log Normal, Gumbel and Generalized Extreme Value (GEV) are presented in Table 1. Chow's general frequency formula which expresses the frequency of occurrence of an event in terms of a frequency factor (K_T) was used to predict the values of ADMR statistically. Frequency analyses formula of Chow (1951) can be reduced to the following form,

$$X_T = \bar{X}\,(1 + C_V K_T) \qquad \dots (2)$$

Table 1: Description of various probability distribution functions

Distribution	Probability density function	Range	Parameters
Normal	$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$	$-\infty < x < \infty$	μ = mean, σ = standard deviation
Log Normal (y = ln x)	$f(x) = \frac{1}{\sigma_x\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{y-\mu_y}{\sigma_y}\right)^2}$	$0 < x < \infty$	μ_y = mean, σ_y = standard deviation
Gumbel	$f(x) = \frac{1}{\alpha} e^{\left[-\frac{x-\mu}{\alpha} - e^{\left(-\frac{x-\mu}{\alpha}\right)}\right]}$	$-\infty < x < \infty$	$\mu = \bar{x} + 0.577\alpha$, $\alpha = \frac{\sigma\sqrt{6}}{\pi}$
Generalized Extreme Value	$f(x) = e^{-\left(1+\xi\frac{x-\mu}{\sigma}\right)^{\frac{-1}{\xi}}}$, $\xi \neq 0$	$1 + \xi\frac{x-\mu}{\sigma} > 0$	ξ = shape parameter, μ = mean

Where, X_T is maximum value of event corresponding to return period T; $\bar{X}$ is mean of the annual maximum series of the data of length N years, C_v is the coefficient of variation and K_T is the frequency factor which depends upon the return period T and the assumed frequency distribution. The expected value of annual maximum daily rainfall for the same return periods were computed for determining the best probability distributions. Methods for estimating probability distribution are as follows:

(i) Normal distribution: The normal distribution is a two parameter unbounded continuous distribution which has been identified as the most important distribution of variables applied to symmetrically distributed data. For normal distribution, the frequency factor K_T can be expressed by the following Chow's equation:

$$K_T = \frac{X_T - \mu}{\sigma} \qquad \dots (3)$$

Equation (3) is the same as the standard normal variate z. Value of z corresponding to an exceedance of p can be calculated determining the value of an intermediate variable w, where,

$$w = \left[\ln\left(\frac{1}{p^2}\right)\right]^{\frac{1}{2}} \quad (0 < p \leq 0.50) \qquad \dots (4)$$

z is then calculated by the following equation:

$$K_T = z = w - \left[\frac{2.515517 + 0.802853w + 0.010328w^2}{1 + 1.432788w + 0.189269w^2 + 0.001308w^3}\right] \qquad \dots (5)$$

When $p > 0.5$, $1-p$ is substituted for p in equation (4) and the value of z computed by equation (5) is given a negative sign.

(ii) Log Normal distribution: Here it is assumed that $Y = \ln X$ is normally distributed by replacing the value of variate X by its natural logarithm. The expected value of rainfall X_T at the corresponding return period T can be computed by:

$$X_T = e^{Y_T} \qquad \dots (6)$$

$$Y_T = \bar{Y}\,(1 + C_{VY} K_T) \qquad \dots (7)$$

Where $\bar{Y}$ is the mean and C_{VY} is the coefficient of variation of Y. The frequency factor can be computed by equation (5) and the following relation:

$$K_T = \frac{Y_T - \mu_Y}{\sigma_Y} \qquad \dots (8)$$

(iii) Gumbel distribution: Frequency factor for this distribution is given by

$$K_T = \frac{(Y_T - 0.577)}{1.2825} \qquad \dots (9)$$

Where Y_T is the reduced variate of given return period T and it is given by

$$Y_T = -\left[0.834 + 2.303 \log\left(\frac{T}{T-1}\right)\right] \qquad \dots (10)$$

(iv) Generalized Extreme Value distribution (Type I): The expected rainfall X_T is calculated by equation (2) and K_T, the frequency factor is calculated by the formula:

$$K_T = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + \ln\left[\ln\left(\frac{T}{T-1}\right)\right]\right\} \qquad \dots (11)$$

Goodness of fit test

Out of the four probability distribution functions tested, the best fit distribution was decided by the chi-squared test for goodness of fit. The chi-squared (χ^2) statistic is given by equation (12),

$$\chi^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i} \quad \dots (12)$$

Where O_i is the observed rainfall, E_i is the expected rainfall and will have chi-squared distribution with *(N-k-1)* degrees of freedom. The chi-squared value was determined for each probability distribution function. The best probability distribution function was that which had the least chi-squared value.

RESULTS AND DISCUSSION

Decadal rainfall analysis

The month and year wise variation of total rainfall with decadal average for Silchar, Assam were analysed and have been presented in Table 2 and Fig. 3, respectively. It revealed that an average annual rainfall of 3272.53 mm had been recorded in Silchar for the period 2003-2012 which is 2.75 times the national average annual rainfall i.e. 1190 mm. In Silchar the highest monthly average rainfall occurred in the month of July (541.07 mm) and lowest in January (7.16 mm). In terms of monthly average rainfall July is tailed by June (535.17 mm), May (485.23 mm), April (448.54 mm) and August (446.30 mm). 2010 has been found to be the rainiest year of the decade with total annual rainfall of 4701.41 mm whereas 2009 had received the lowest amount of rainfall in the entire decade (2331.2 mm). The decadal standard deviation (S.D) of the annual rainfall was found to be 679.73 mm. It was observed that 5 years (50%) had received annual rainfall more than the decadal average rainfall (Fig. 3). During the decade, there was only one abnormal (wet) year (2010) which had received total annual rainfall more than 3952.26 mm (Mean + S.D) i.e. 4701.41 mm and two drought or deficit years which received total annual rainfall less than 2592.79 mm (Mean - S.D) i.e. 2006 (2542.31 mm) with 1.95% rainfall

Table 2: Summary of the year wise monthly rainfall observed and decadal statistics of the study area

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Average
Month	**Rainfall (mm)**										
Jan	0	0	0.8	0	0	36.8	0	0	8.4	25.6	7.16
Feb	9.1	0	78.2	61.1	77.1	21.5	54.7	8.4	20	23.2	35.33
Mar	95	30	428.2	0.7	73.2	236.8	164.8	307.2	114.5	174.4	162.48
Apr	378.9	1159.4	323.8	192.7	502	51.6	324.3	649.19	369.31	534.2	448.54
May	290.8	514.4	544.38	532.21	446.02	363.5	254.3	881.93	577.7	447.1	485.23
Jun	661.1	406.4	318.56	704.6	540.7	386.1	467.62	659.36	399	808.3	535.17
Jul	388.3	667.2	662.14	581.4	398.5	651.5	541.88	586.8	555.4	377.6	541.07
Aug	402	416	468.9	153.7	517.2	820.4	159.4	433.26	532.6	559.5	446.30
Sep	406.5	507.2	160.5	216	521.3	396.8	217.6	937.97	257.4	275.64	389.69
Oct	254.4	155.8	318.5	94.5	281.2	183.2	146.6	181.7	52.2	215.8	188.39
Nov	0	0	0	5.4	99.2	0	0	11.6	0	63.8	18
Dec	72	0	32.8	0	2.8	0	0	44	0	0	15.16
Total	2958.1	3856.4	3336.78	2542.31	3459.22	3148.2	2331.2	4701.41	2886.51	3505.14	**3272.53**

(Source: Silchar Water Resource Department records (station at E and D Colony, Silchar))

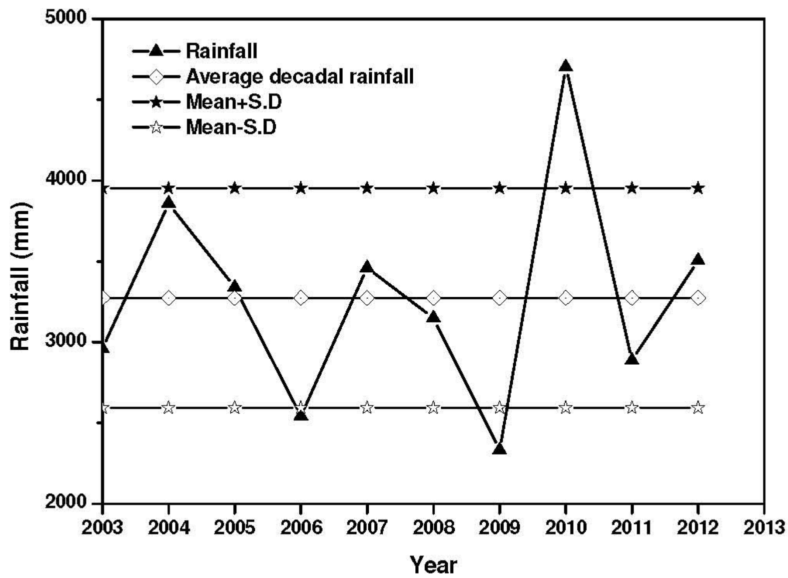

Fig. 3: The variability of total annual rainfall with decadal mean rainfall in the study area

deficiency and 2009 (2331.2 mm) with 10.08% rainfall deficiency.

Statistical analysis of annual one day maximum rainfall

Annual one day maximum rainfall (ADMR) recorded at Silchar (2003-2012) with corresponding date were analysed and have been presented in Table 3. The highest and lowest values of ADMR were found to be 180 mm on 16th April 2004 and 110.4 mm on 17th June 2007, respectively. The year 2004 had experienced devastating flood in Silchar due to excessive rainfall and the over-flooding of river Barak due to numerous sudden storm events (Technical Report and Atlas of Silchar, 2014). Excessive one day rainfall along with the fact that the river was already conveying prior to the storm event, resulted in inundation of Silchar area by river Barak.

Table 3: One day maximum rainfall for the period 2003-2012

Sl. No.	Year	Date	Rainfall (mm)
1	2003	11-Oct	138.0
2	2004	16-Apr	180.0
3	2005	25-Oct	150.7
4	2006	11-Sep	114.4
5	2007	17-Jun	110.4
6	2008	26-Jul	129.2
7	2009	02-Jul	118.0
8	2010	08-Oct	140.8
9	2011	21-May	120.2
10	2012	30-Aug	144.2

Various statistical parameters of ADMR were determined and have been summarized in Table 4. The average ADMR for the time duration mentioned above was found as 134.59 mm with a standard deviation of 21 mm, coefficient of variation (C_v) 15.6% and coefficient of skewness (C_s) 1.03%. The positive value of C_s indicates that the distribution is slightly right-tailed and the mass of the distribution (here ADMR) is concentrated towards the left i.e. towards the initial years of the decade. It was also observed that 5 years (50%) had received ADMR above the average, but no general trend in occurrence of rainfall was perceived during the study period. The statistical parameters stated above come to aid for computing ADMR from different probability distribution functions.

Table 4: Statistics of maximum one-day annual rainfall of Silchar (2003-2012)

Parameter	Values
Maximum value (mm)	180.00
Minimum (mm)	110.40
Average one day maximum rainfall (mm)	134.59
Standard deviation (mm)	21.00
Coefficient of variation (C_v)	15.60
Coefficient of skewness (C_s)	1.03

Probability analysis of ADMR

The return period of ADMR for 2003-2012 was calculated using Weibull's method (Eq. 1). The expected ADMR for different probability distributions such as Generalized Extreme Value (GEV), Normal, Log Normal (LN) and Gumbel were calculated for the return periods 1.1, 1.22, 1.38, 1.57, 1.83, 2.2, 2.75, 3.67, 5.5 and 11 years and have been presented in Table 5. The expected ADMR for the different probability distributions have also been graphically presented in Fig. 5. From the Figure, it can be observed that the estimated ADMR for the four different probability distribution functions follow the same trend as observed rainfall.

Testing goodness of fit of probability distribution

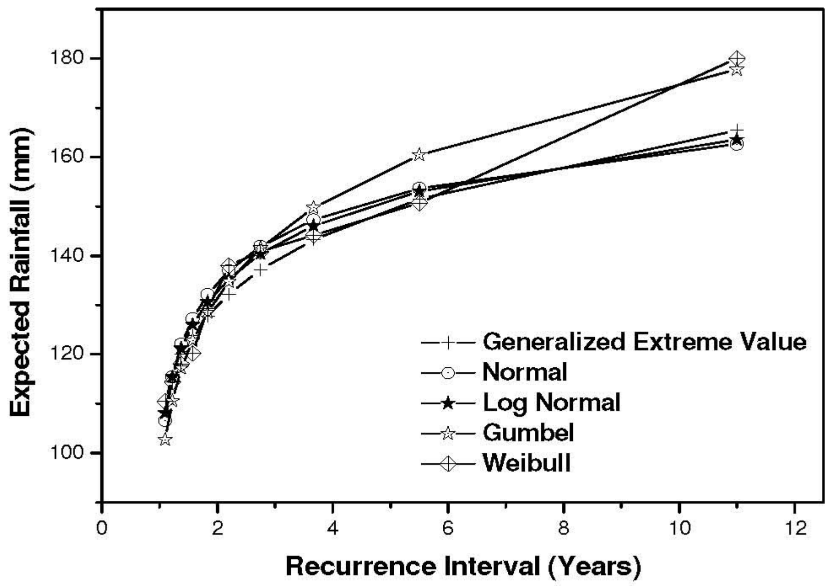

Fig. 4: Estimated annual one day maximum rainfall for different return periods

Table 5: Expected rainfall and Chi-square values for different probability distributions function at different return period for different distributions

		Expected one day maximum rainfall, mm (E)					$(O-E)^2/E$			
P (%)	T (years)	GEV	Normal	LN	Gumbel	Weibull (O)	GEV	Normal	LN	Gumbel
9.09	11	165.41	162.63	163.58	177.79	180	1.287	1.855	1.648	0.027
18.18	5.5	151.48	153.66	153.1	160.46	150.7	0.004	0.057	0.038	0.594
27.27	3.67	143.25	147.29	146.06	149.73	144.2	0.006	0.065	0.024	0.204
36.36	2.75	137.16	141.9	140.36	141.55	140.8	0.097	0.009	0.001	0.004
45.45	2.2	132.2	136.98	135.35	134.72	138	0.254	0.008	0.052	0.080
54.55	1.83	127.81	132.15	130.6	128.53	129.2	0.015	0.066	0.015	0.003
63.64	1.57	123.79	127.24	125.96	122.75	120.2	0.104	0.390	0.263	0.053
72.73	1.38	119.95	122.07	121.24	117.14	118	0.032	0.136	0.087	0.006
81.82	1.22	115.52	115.4	115.41	110.53	114.4	0.011	0.009	0.009	0.136
90.91	1.1	110.4	106.55	108.11	102.69	110.4	0	0.139	0.049	0.579
						Total	1.810	2.732	2.185	1.686

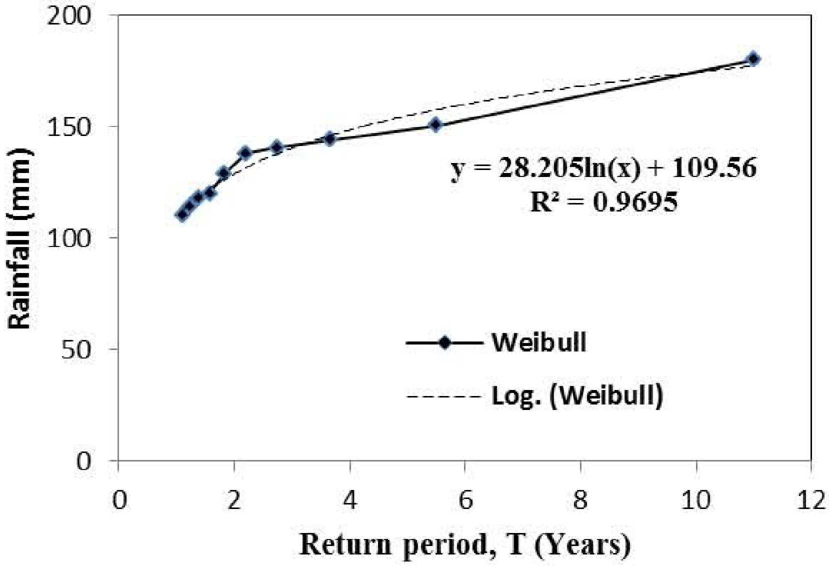

Fig 5: Annual one day maximum rainfall vs. return period as estimated by Weibull's method.

All four probability distribution functions were tested by χ^2 value (Eq. 12) which compares how well theoretical distributions can be fit to the empirical distribution. A higher computed test value by chi-squared method signifies that the observed and expected values aren't close enough and hence a poor fit to the data, and otherwise it's a good fit (Al-Houri *et al*., 2014). The chi-squared values for the different probability distributions have been presented in Table 5. The analysis revealed Gumbel distribution to be the one with the lowest chi-squared value (1.686) among the four distributions tested for good fit of data and hence the best probability distribution for predicting ADMR. The second, third and fourth good-fit distributions were GEV, LN and Normal with 1.810, 2.185 and 2.732, respectively. According to Gumbel distribution, it can be expected that a minimum rainfall of 102.69 mm can be received with 90.19% probability and a return period of 1.1 years and a maximum rainfall of 177.79 mm can be expected in Silchar with a probability of 9.09% after a return period of 11 years. A maximum rainfall of 128.53 mm is expected to occur at every 1.83 years and 54.55% probability which is approaching the mean ADMR.

Regression analysis

Regression analysis was developed from the observed ADMR against the corresponding return periods by Weibull's method. The trend analysis for predicting the one day maximum rainfall for different return period was carried out and have been presented in Fig.5. It was observed that the logarithmic trendline gave the better coefficient of determination (R^2= 0.9695) than all others and the equation was $y = 28.205\ ln(x) + 109.56$, where y is ADMR, mm and x is return period, years.

CONCLUSION

Spatial and temporal variability of rainfall in Silchar, Assam can be attributed to natural as well as anthropogenic reasons. The mean value of ADMR was found to be 134.59 mm with standard deviation, coefficient of variation and coefficient of skewness 21 mm, 15.6% and 1.03%, respectively. Out of the four probability distributions functions (GEV, Normal, LN, Gumbel) tested for frequency analysis of ADMR and further tested for goodness of fit by chi-squared method, Gumbel distribution was found to be the best fit due to its least value of χ^2 (1.686). For a return period of 11 years and 9.09%

probability, maximum expected ADMR is 177.79 mm. This study ushers in a prediction of ADMR which can aid in designing small and medium soil and water conservation structures, drains, culverts and field diversions.

ACKNOWLEDGEMENT

The authors are grateful to *Silchar Water Resource Department (Government of Assam)* for providing the data to conduct this study.

REFERENCES

1. *Agarwal, M.C., Katiyar, V.S, Babu, R. 1988. Probability analysis of annual maximum daily rainfall of U.P. Himalaya. Indian Journal of Soil Conservation, 16(1): 35-43.*

2. *Al-Houri, Z., Al-Omari, A., Saleh, O. 2014. Frequency analysis of annual one day maximum rainfall at Amman Zarqa Basin, Jordan. Civil and Environmental Research, 6(3): 44-57.*

3. *Bhakar, S.R., Iqbal, M., Devanda, M., Chhajed, N., Bansal, A.K. 2008. Probability analysis of rainfall at Kota. Indian Journal of Agricultural Research, 42: 201 - 206.*

4. *Rao, A.R., Kao, S. Statistical analysis of Indiana rainfall data final report. 2006. FHWA/IN/JTRP- 006/8, Purdue University, USA.*

5. *Ray, I.P.L., Bora, P.K., Singh, A.K., Singh, N.J., Singh, R., Feroze, S.M. 2014. Rainfall characteristics, pattern and distribution of central Meghalaya. Journal of Indian Water Resources Society. 34(2): 9-16.*

6. *Rizvi, R.H., Singh, R., Yadav, R.S., Tewari, R.K., Dadhwal, K.S, Solanki, K.R. 2001. Probability analysis of annual maximum daily rainfall for Bundelkhand of Uttar Pradesh. Journal of Soil Conservation. 29(3): 259-262.*

7. *Sharma, M.A., Singh, J.B. 2010. Use of probability distribution in rainfall analysis. New York Science Journal, 3(9): 40-49.*

8. *Singh, B., Rajpurohit, D., Vasishth, A., Singh, J. 2012. Probability analysis for estimation of annual one day maximum rainfall of Jhalarapatan area of Rajasthan, India. Plant Archives, 12(2): 1090-1100.*

9. *Status Paper of Department of Agriculture, Cachar district, Assam. 2013.*

10. *Subramanya, K. 2009. Engineering Hydrology. 3rd edition, Tata McGraw-Hill Publishers, New Delhi.*

11. *Suresh, R. 2005. Watershed Hydrology. 2nd edition, Standard Publishers Distributors, Delhi.*

12. *Technical Report and Atlas on Remote Sensing and GIS Based Inputs for Hazard Risk Vulnerability Assessment of Guwahati City, Silchar, Dibrugarh Towns and Dhemaji District, Assam, Volume II. 2014.*

13. *Vivekanandan, N. 2009. Comparison of T-year rainfall using frequency analysis approach. Journal of Indian Water Resources Society. 29(1): 22-27.*